SinBerBEST

Singapore-Berkeley Building Efficiency and Sustainability in the Tropics

Simulations of Innovative Solutions for Energy Efficient Building Façades

Aashish Ahuja
PhD candidate
Mechanical Engineering
UC Berkeley

National Research Foundation Singapore
CREATE Campus for Research Excellence And Technological Enterprise
BEARS Berkeley Education Alliance for Research in Singapore Limited
Berkeley University of California
NUS National University of Singapore

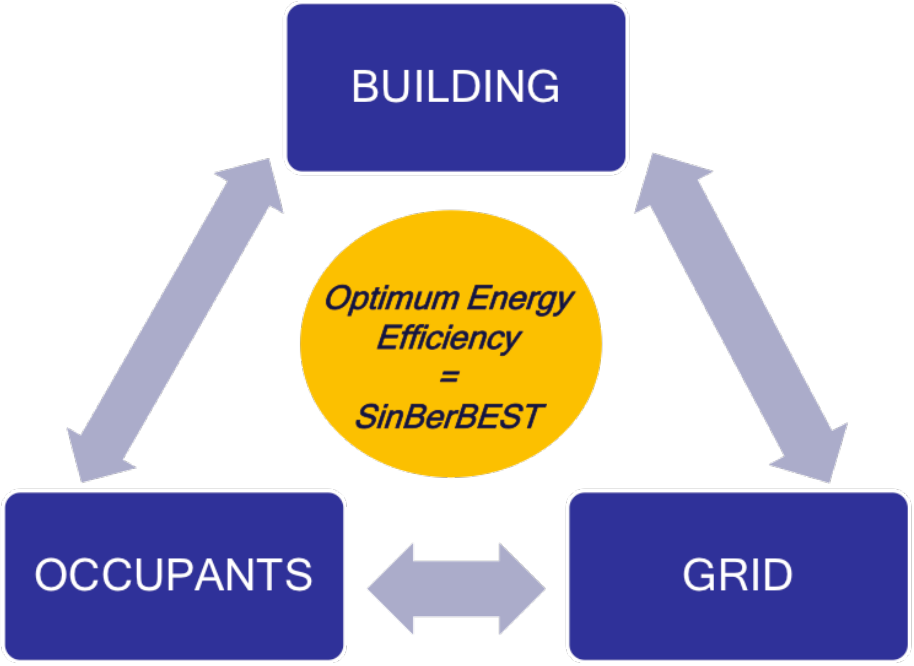
Outline

- Introduction
- Proposed Technology
- Methods and Simulation Results
- Future Work

Introduction

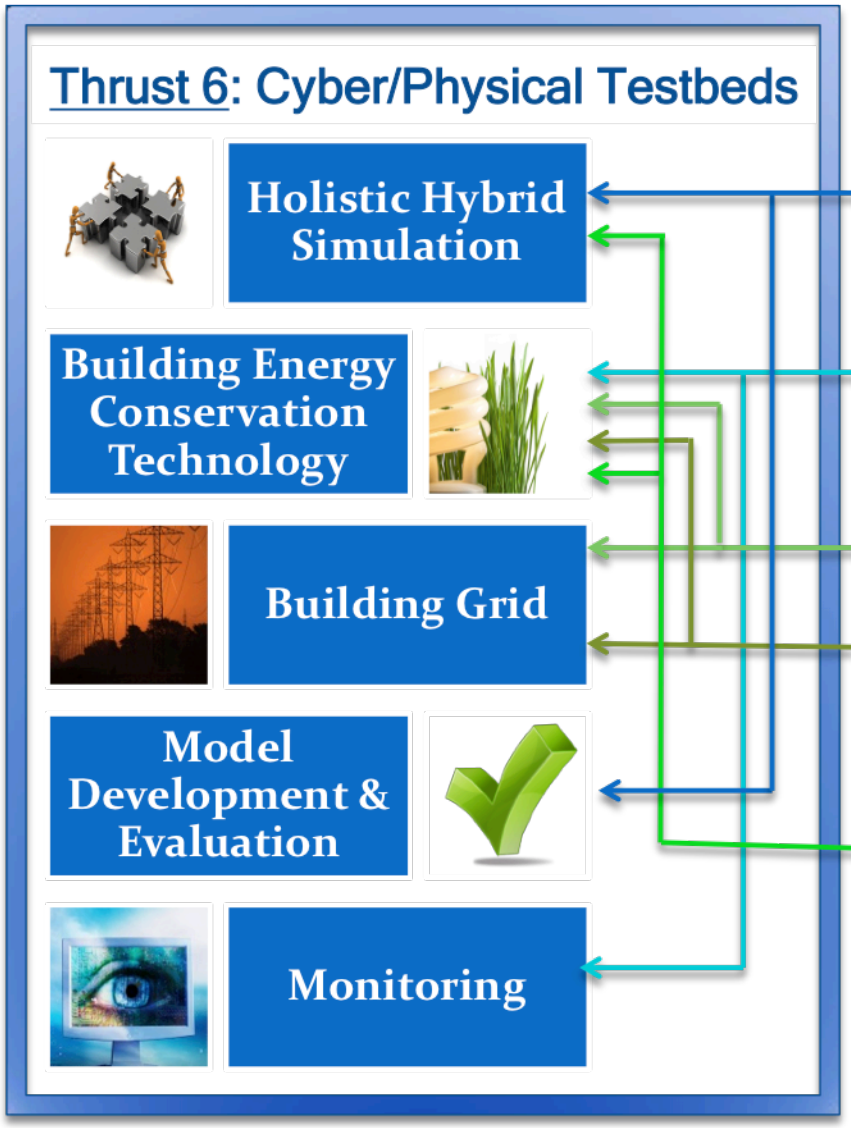
Introduction

1. Working on a multi-disciplinary project called SinBerBEST.
2. Seeks cooperative interaction between the grid, building and occupants.
3. Optimizing energy consumption, productivity, emissions, comfort, productivity and the entire building lifecycle.



4. My work: Analyze new energy efficient building material for façades.

SinBerBEST Research Thrusts



Thrust 1: Sensing, Data Mining and Modeling

Thrust 2: Multi-Level Optimal Control

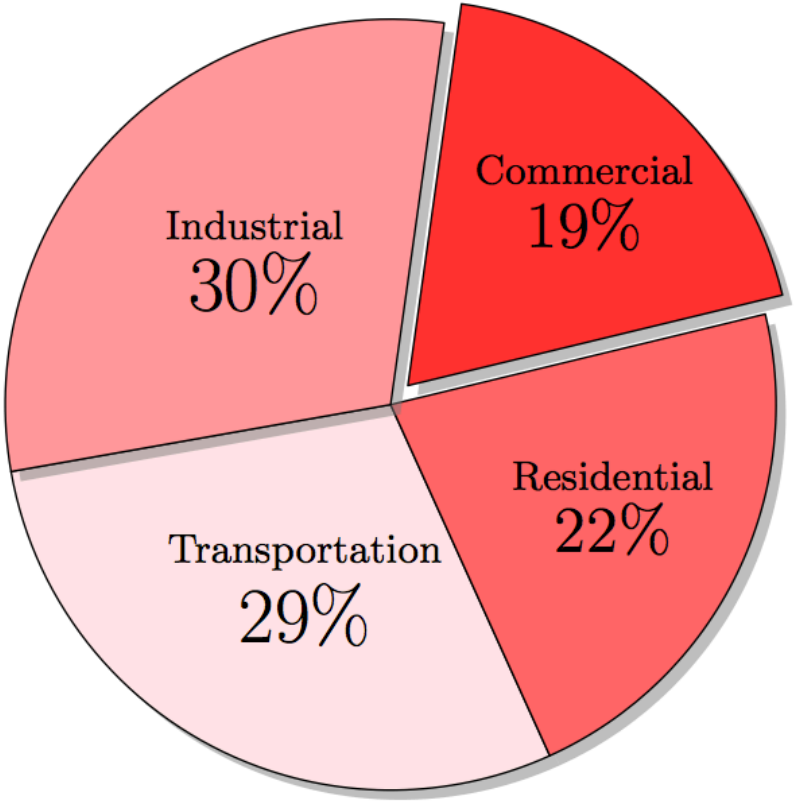
Thrust 3: High Confidence Building Operating System

Thrust 4: Human-Building Interaction & the Environment

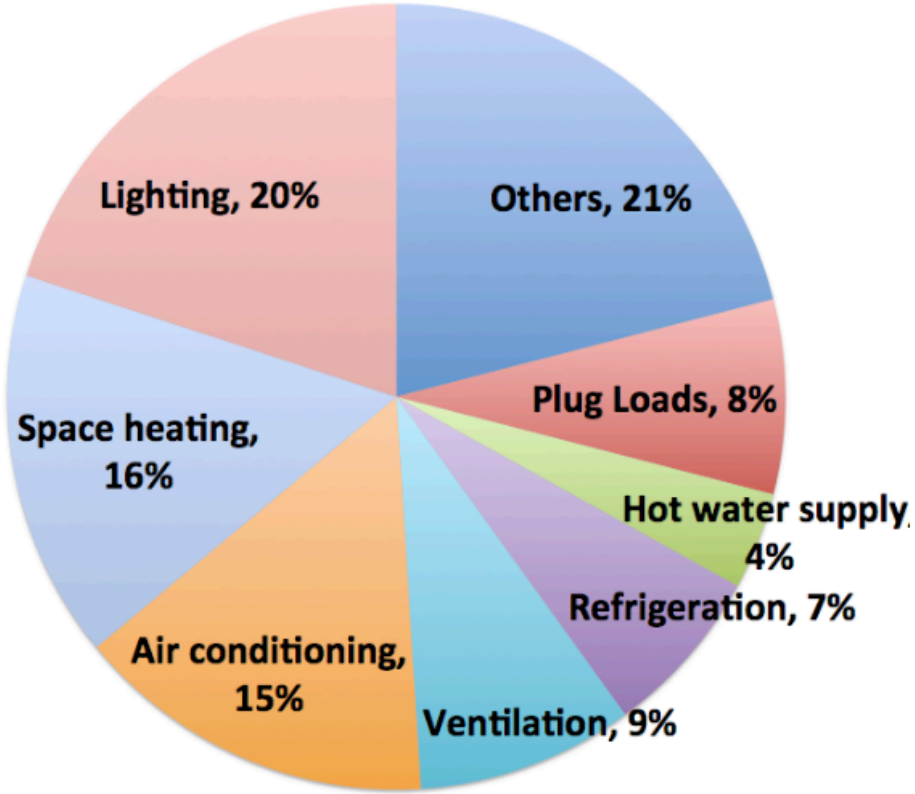
Thrust 5: Material, Design and Lifecycle

Proposed Technology

Energy Usage



a) Sources of energy use



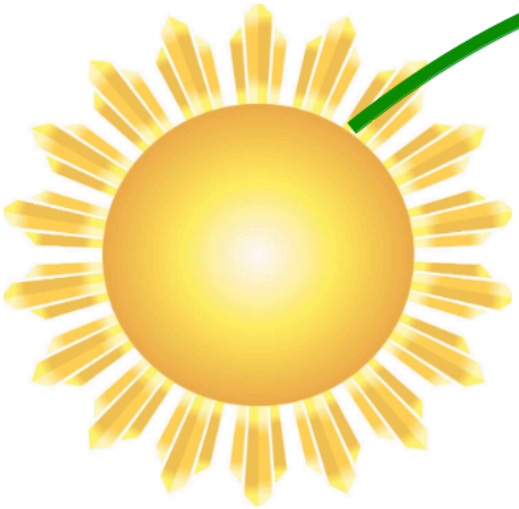
b) Energy consumption in commercial buildings

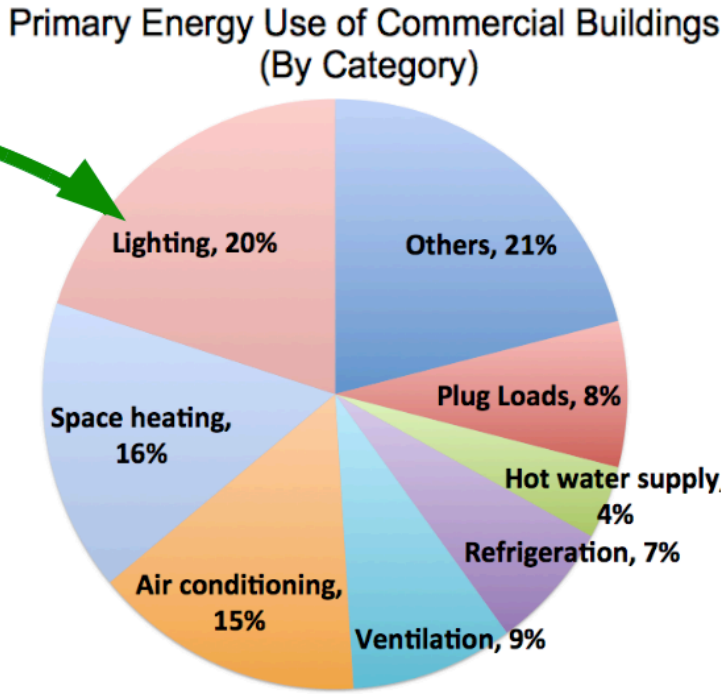
Images Source: DOE 2011

Sunlight in buildings

Sunlight (positive)

Substitute indoor lights

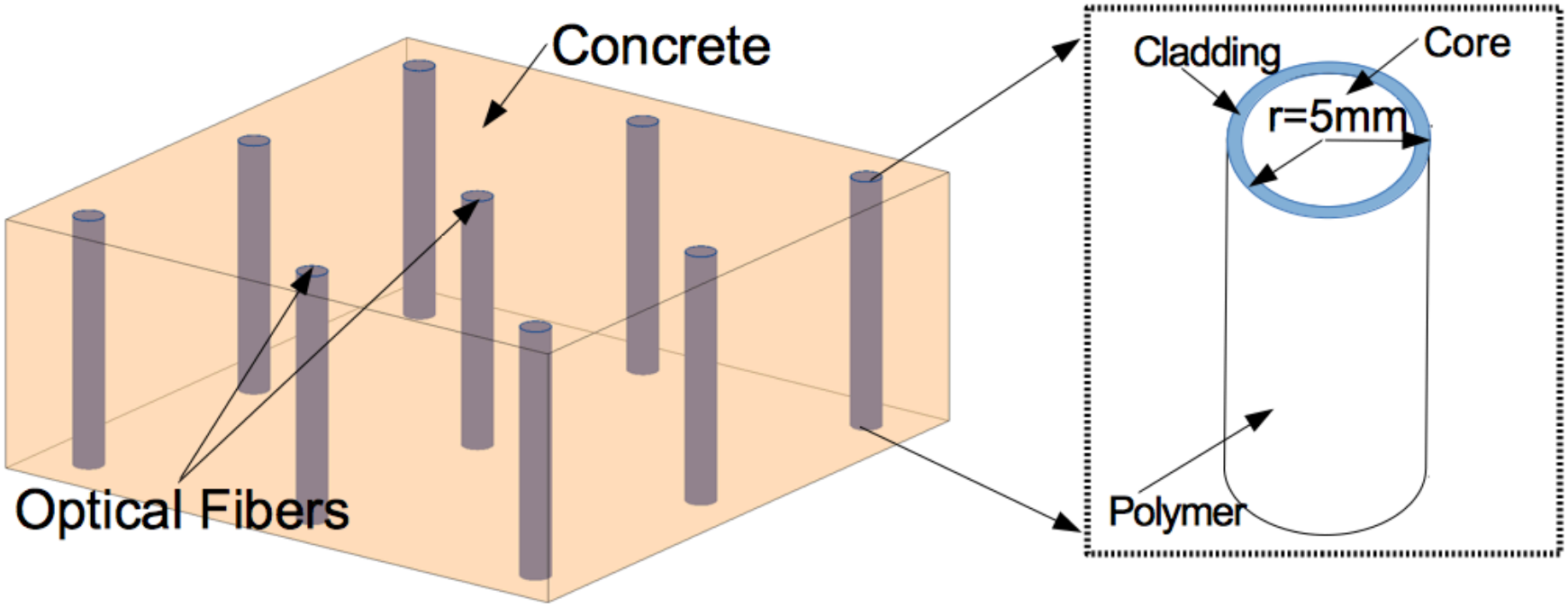




Source : DOE 2011 Buildings Energy Data Book

Proposed building material

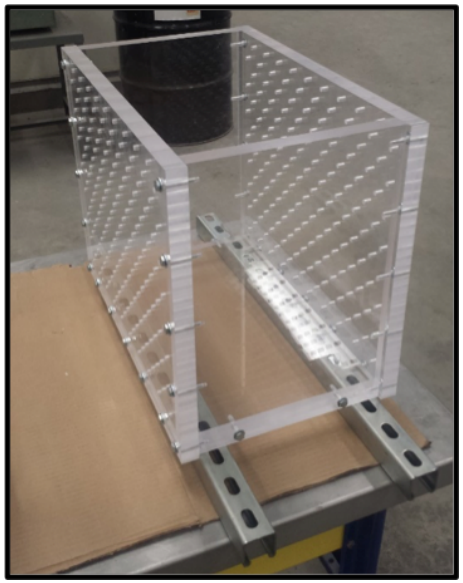
The proposed building element is referred to as
‘Translucent Concrete Panel’



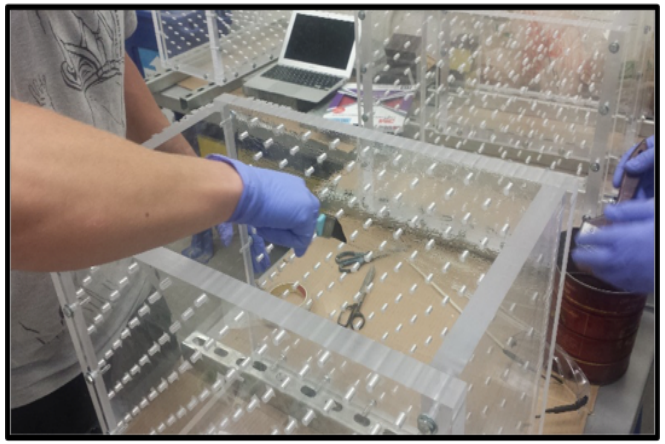
Features of TC panels

- Structural panels that can support buildings.
- Fibers channel diffused daylight into the room.
- Sunlight into room can be controlled by varying volumetric ratio of fibers.
- The panels can be coupled with other technologies [Mosalam13].

Construction Procedure: Part A

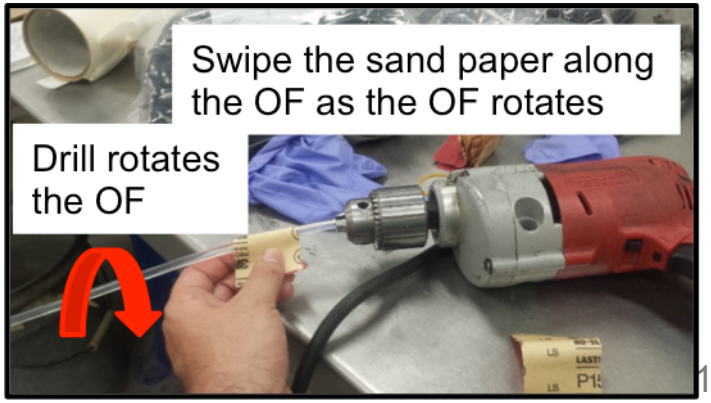


a) Preparing the acrylic formwork

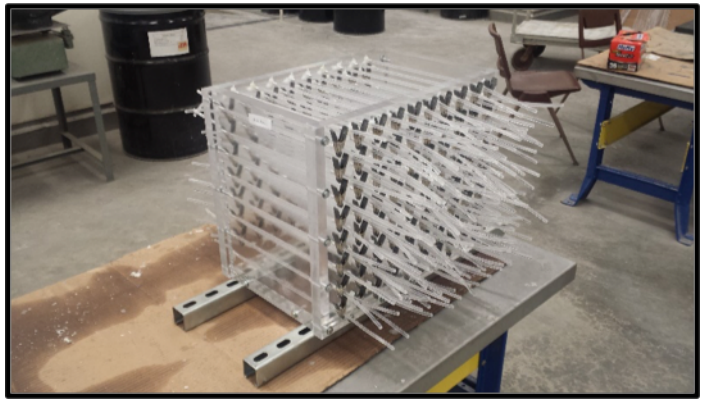


b) Greasing the formwork

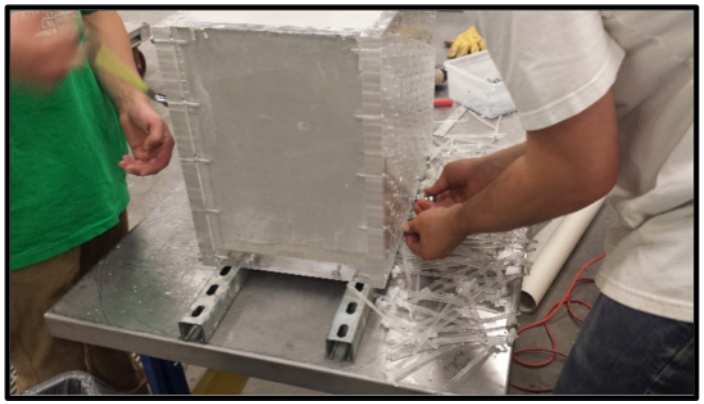
c) Roughening fibers for Better bonding



Construction Procedure: Part A



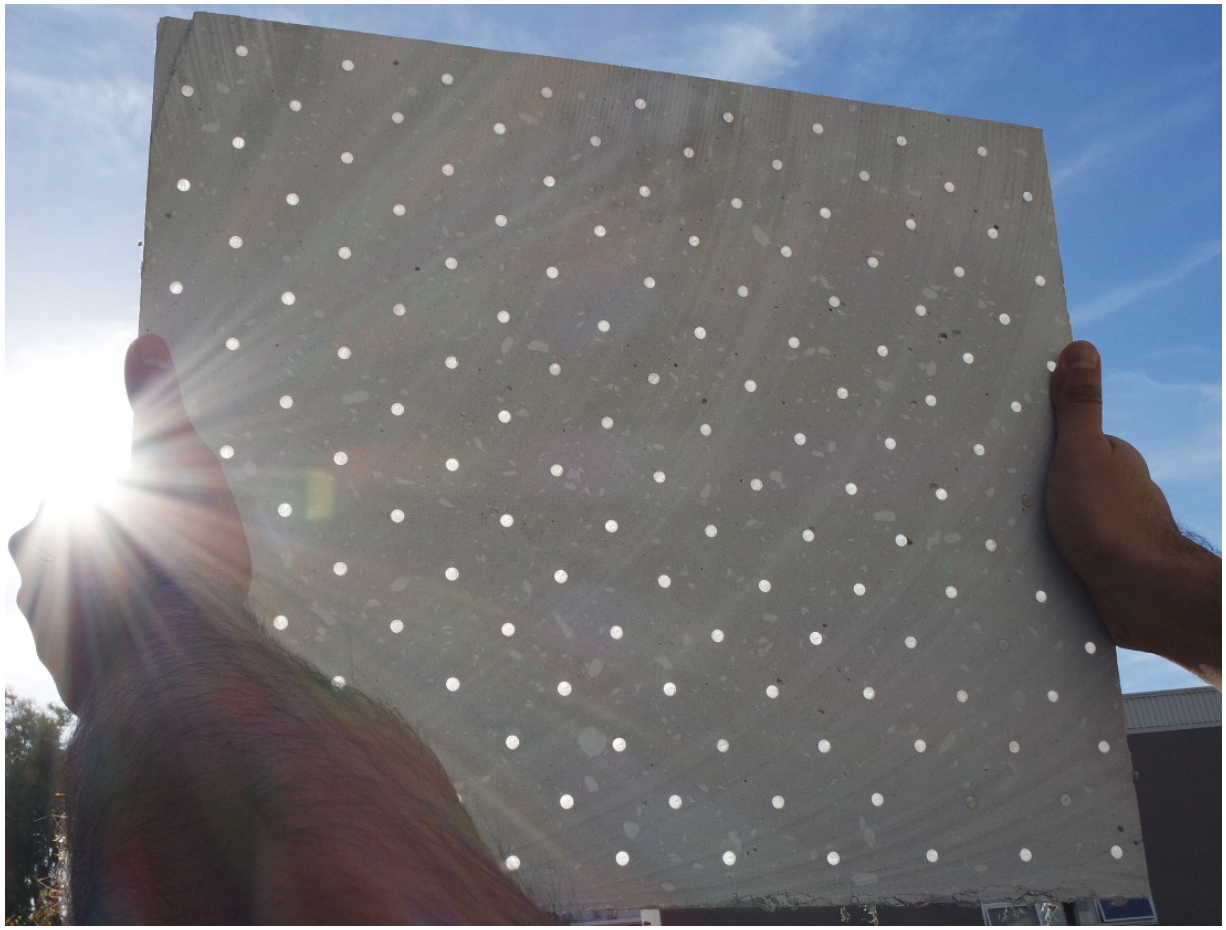
d) Inserting fibers and clamping them



e) Casting concrete

f) Cutting concrete blocks into panels

Translucent Concrete



Sample of TC panel held against Sun

Methods and Results:
Optical and Thermal Behavior

Optical behavior: Ray tracing

- Ray tracing tracks light rays across different media.

- Trajectory followed by rays is continuous. Expressed in form of differential equation.

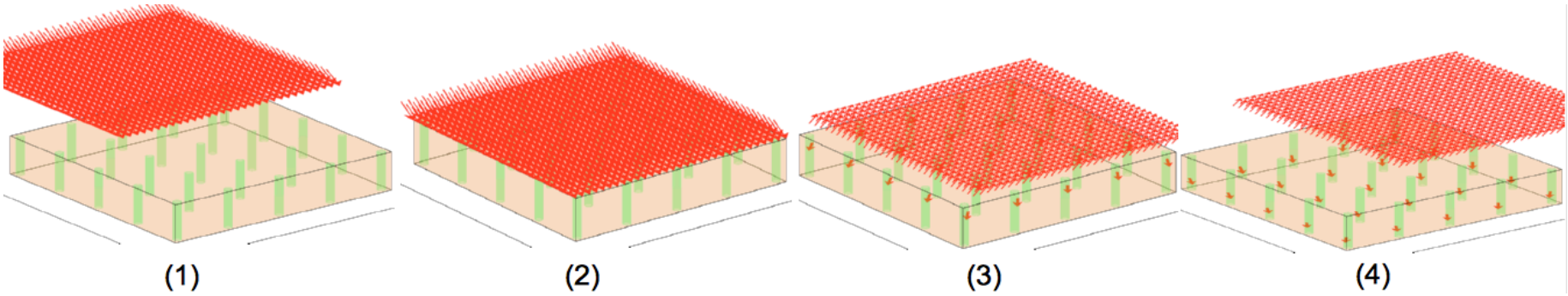
Eikonal equation

$$\frac{d}{ds}\left[n(x,y,z)\frac{d\boldsymbol{R}}{ds}\right] = \nabla n$$

where: $\frac{d\mathbf{R}}{ds} = [\cos\alpha, \cos\beta, \cos\gamma] = \mathbf{A}$, *n(x, y, z)* : Refractive Index at (x, y, z)

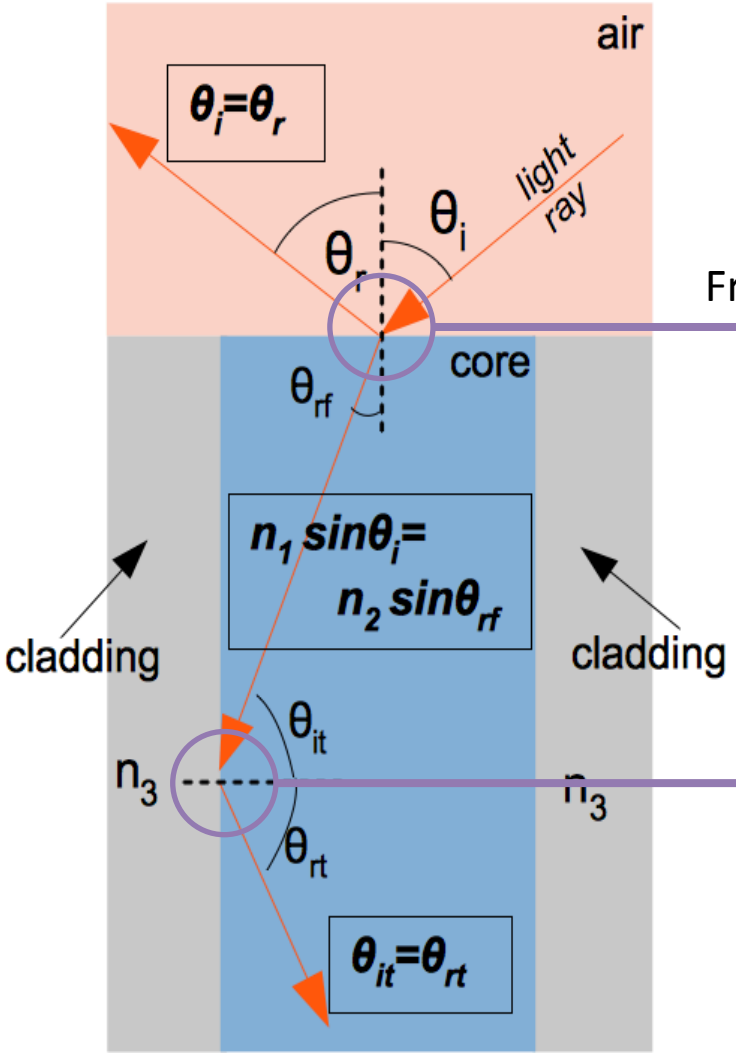
Marching rays

- For each ray, the equation is discretized spatially.
- Algorithm developed in Fortran and Python.
- At each time step, the location and velocity of ray is updated.



Forward ray marching in TC panel

Light interaction with fibers

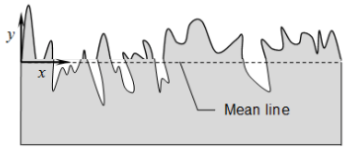


Section of optical fiber

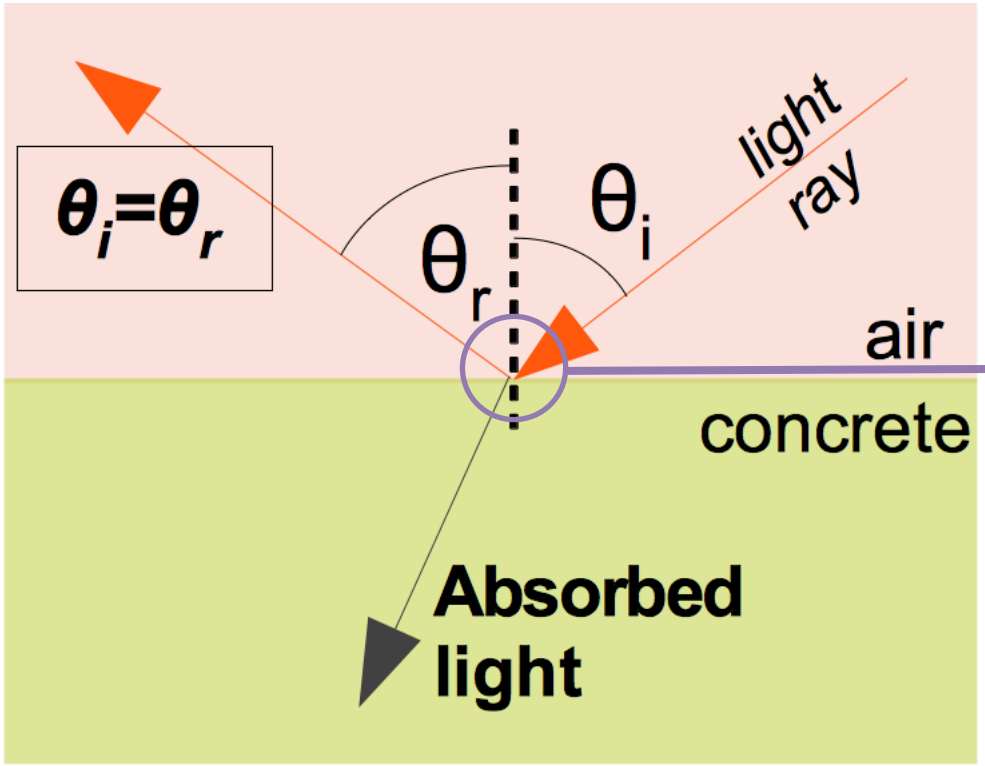
Fresnel's Laws → Reflection and Refraction

Total Internal Reflection

Other losses: 1) Light scattering
2) Absorption
3) Surface roughness of fibers



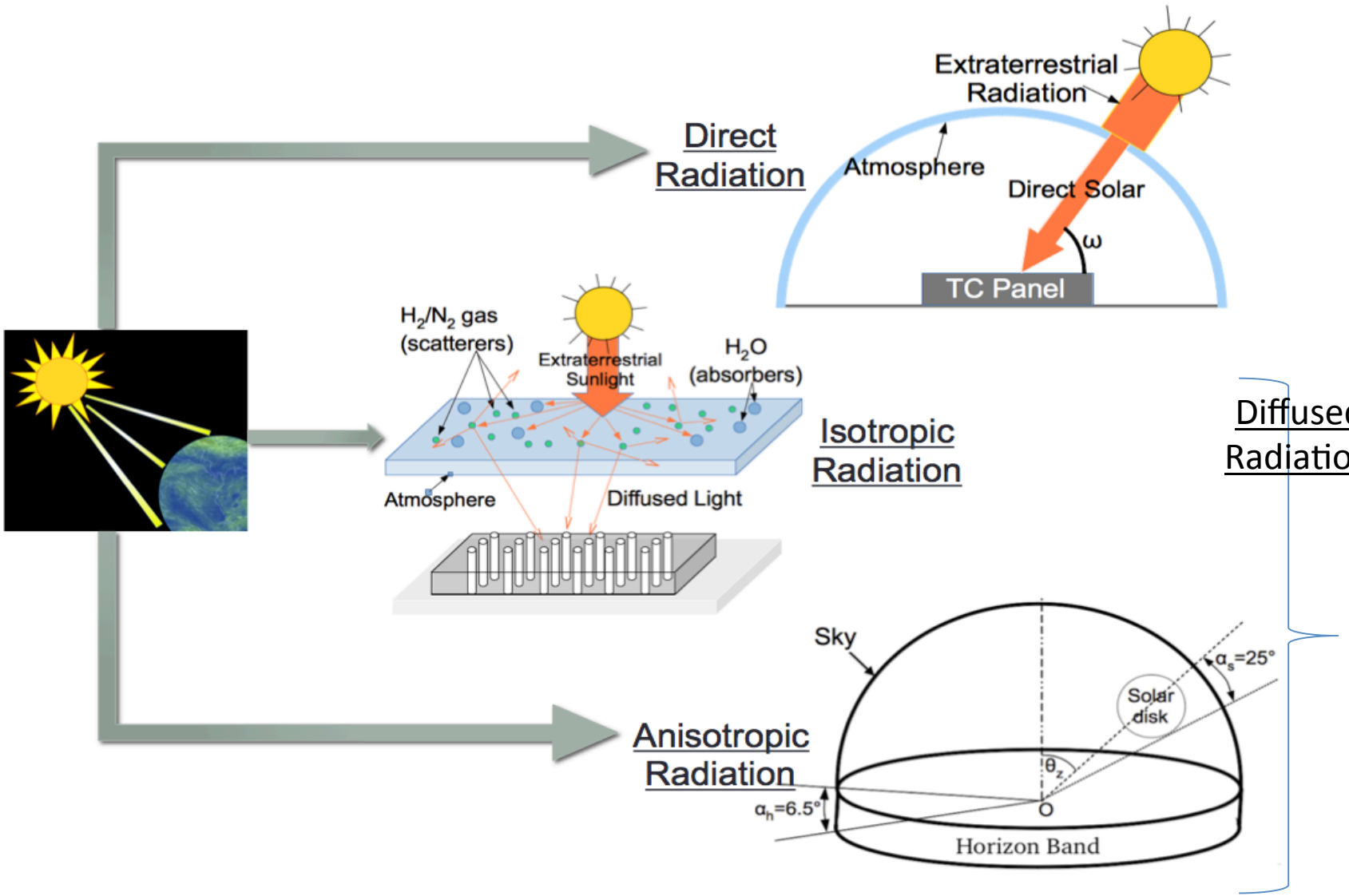
Light interaction with concrete



Reflection and Absorption

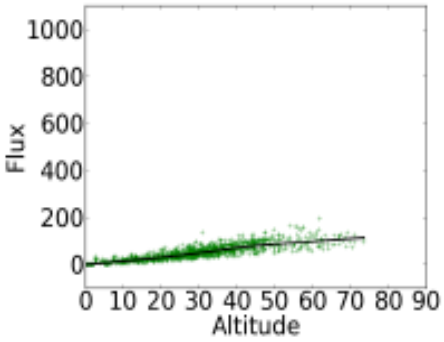
Concrete part of TC

Sunlight distribution model

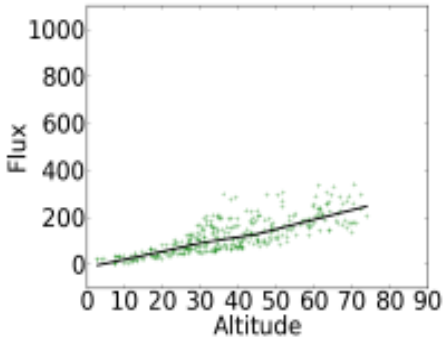


Perez Sky Distribution Model [Perez87]

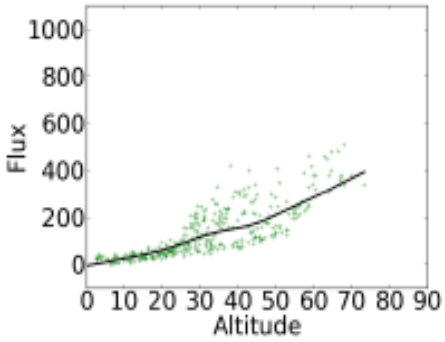
Sky cover for Berkeley



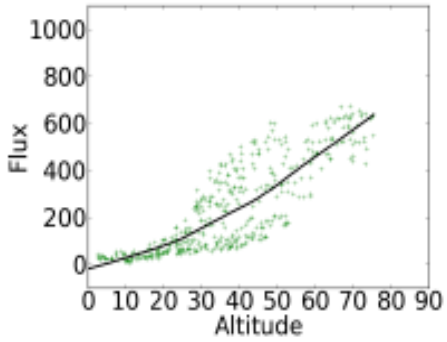
(a) ϵ bin #1



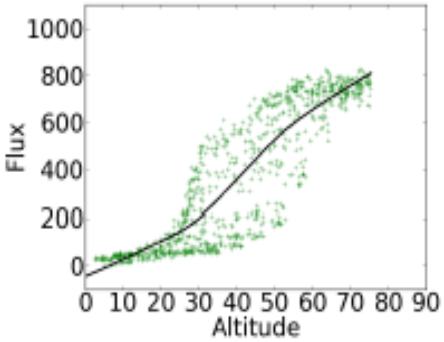
(b) ϵ bin #2



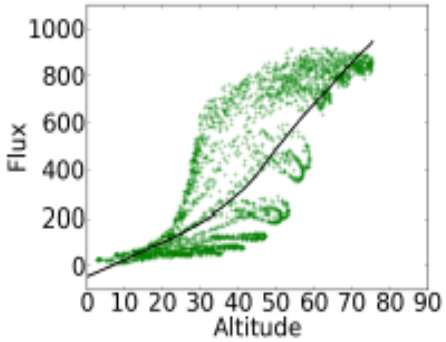
(c) ϵ bin #3



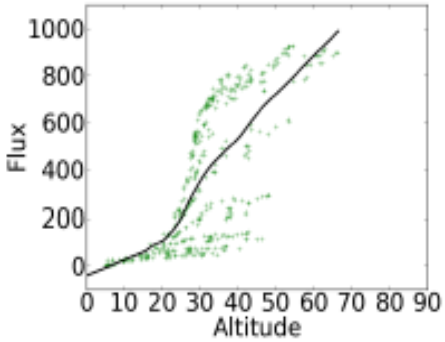
(d) ϵ bin #4



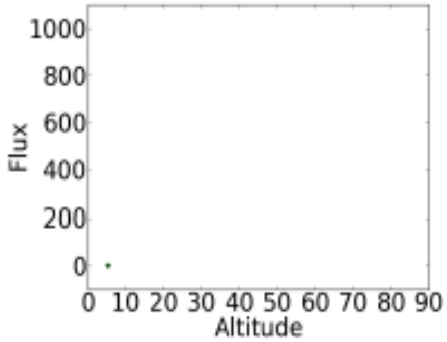
(e) ϵ bin #5



(f) ϵ bin #6



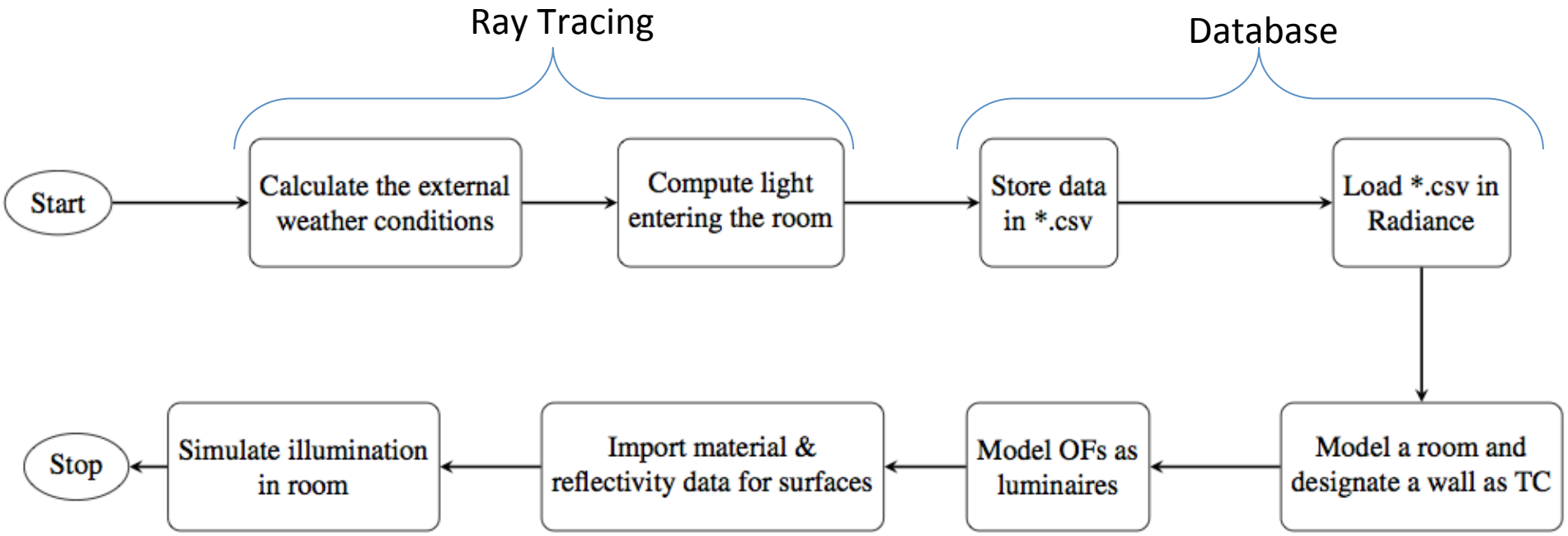
(g) ϵ bin #7



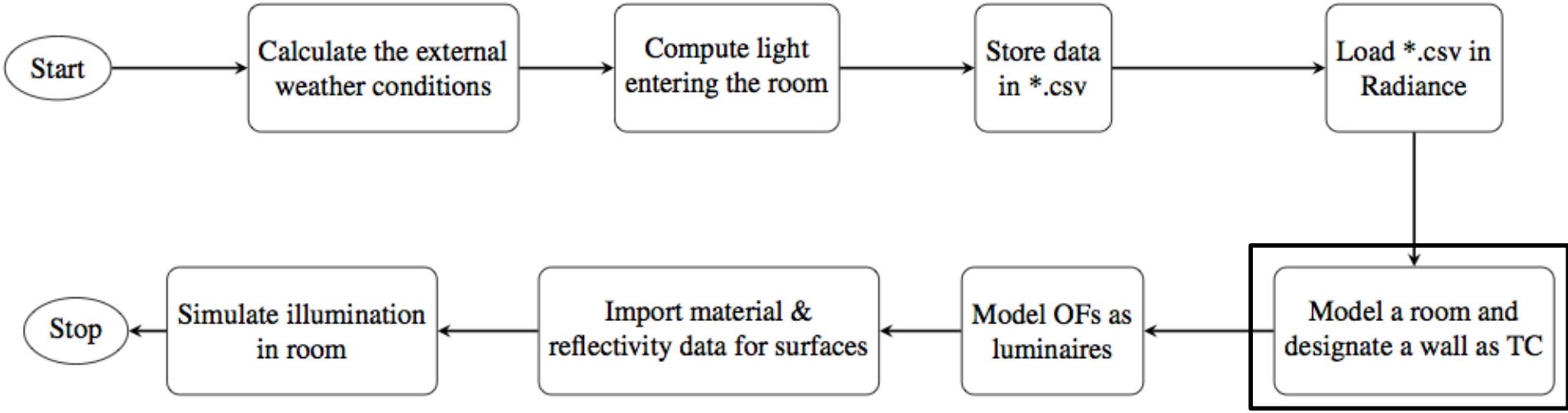
(h) ϵ bin #8

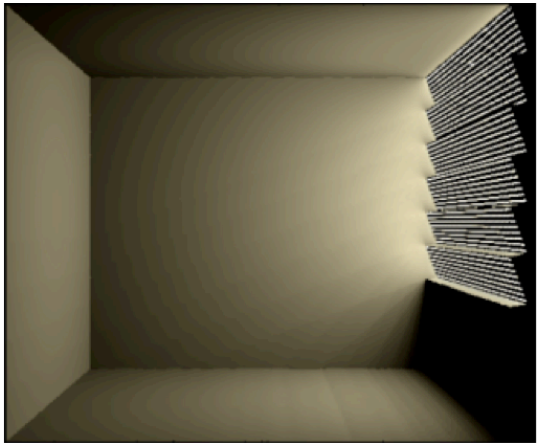
Variation of the solar flux with sun's position.
{1: least clear; 8: most clear}

Illumination Calculations

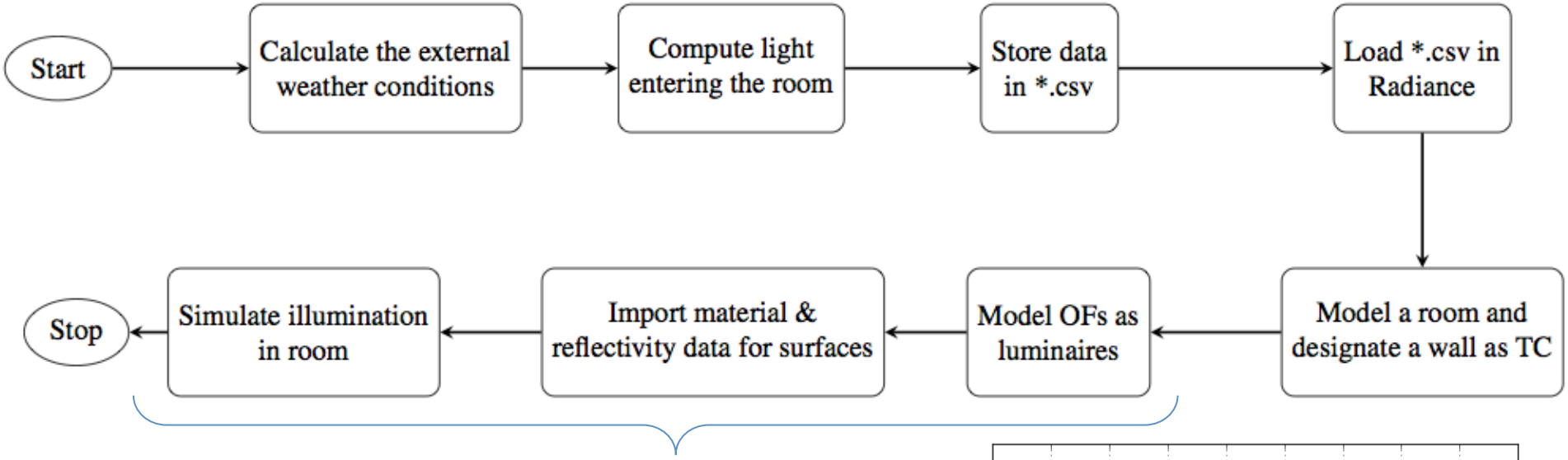


Illumination Calculations



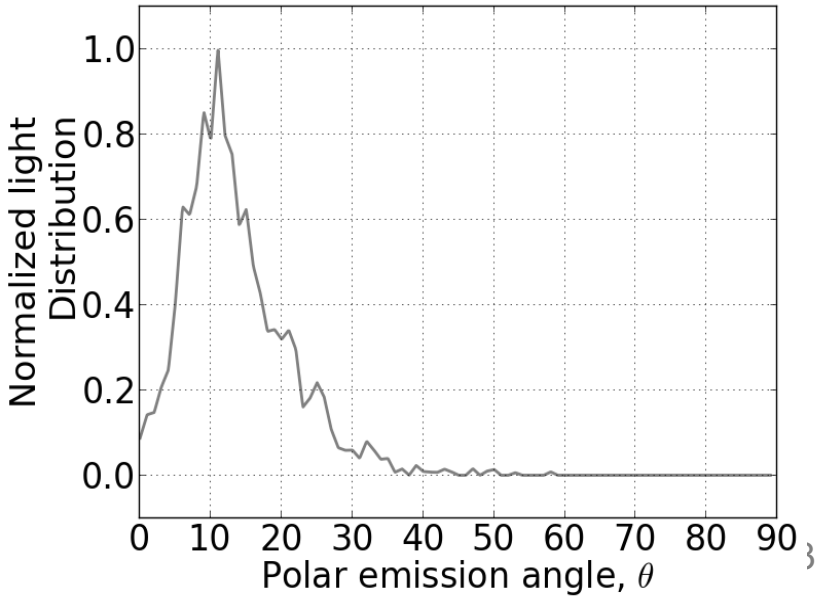


Illumination Calculations



1) Optical fibers are modeled as light emitting luminaires [Ahuja14, Ahuja151].

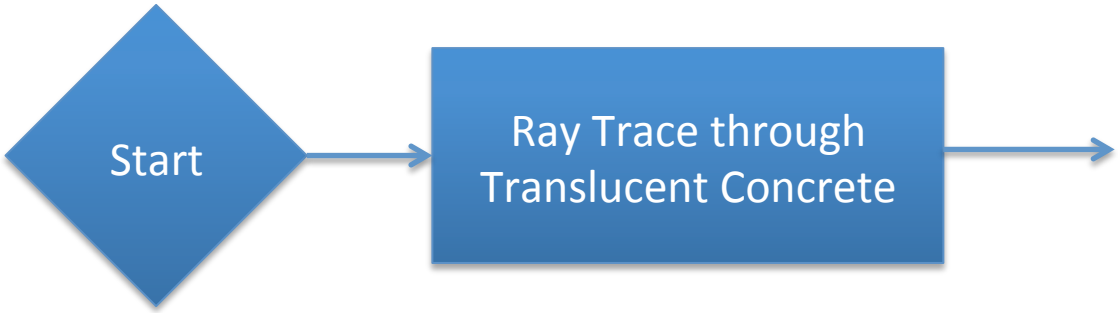
2) Illumination can be calculated at any point inside the room.



Energy calculations

- Illumination calculations are further extended to include occupant behavior.
- The occupant behavior decides light switching activity.
- For the times light is switched off, electrical energy is conserved.

Algorithm for Energy Calculations



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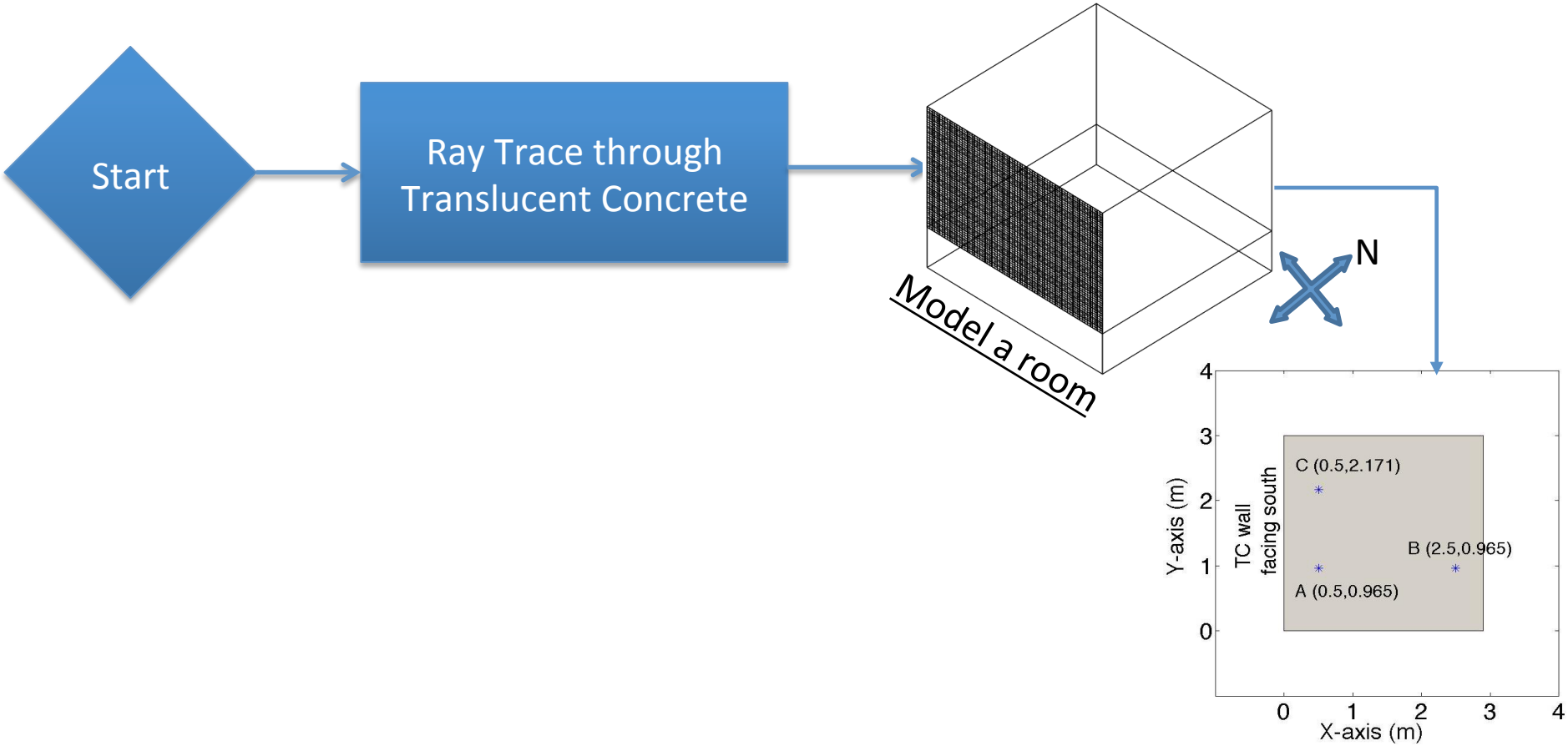

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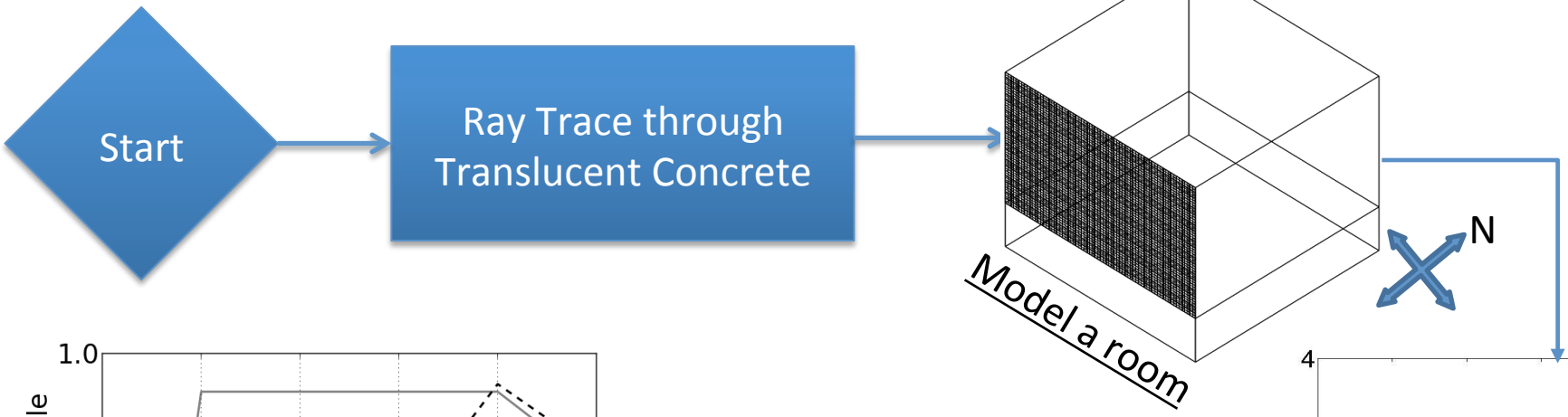
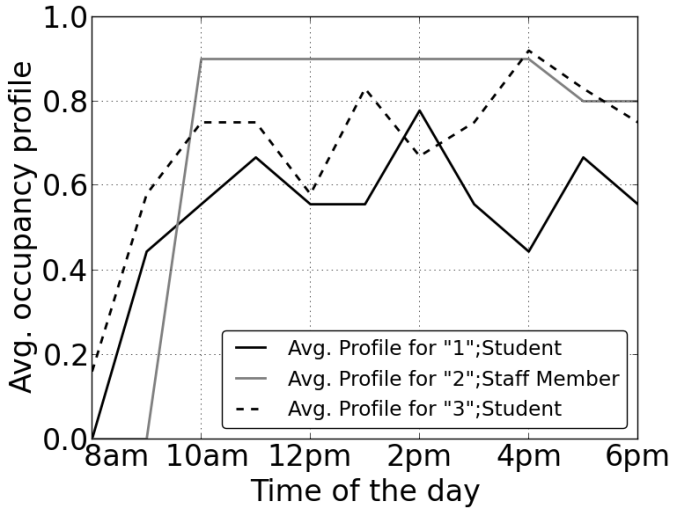
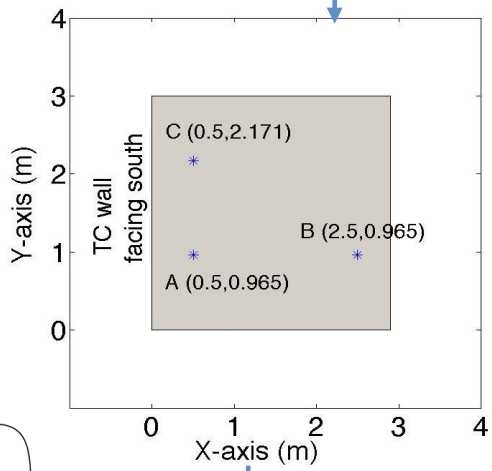
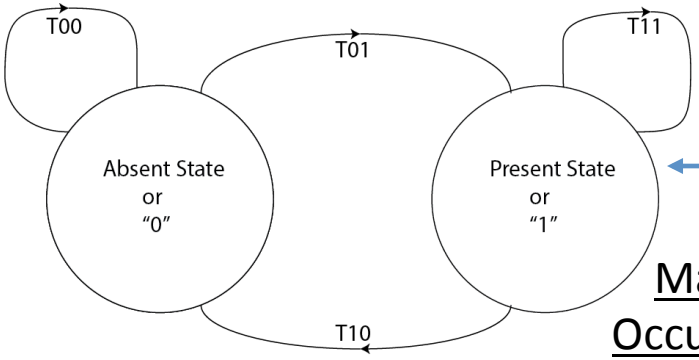




Monday occupancy profile between 8*am* and 6*pm*



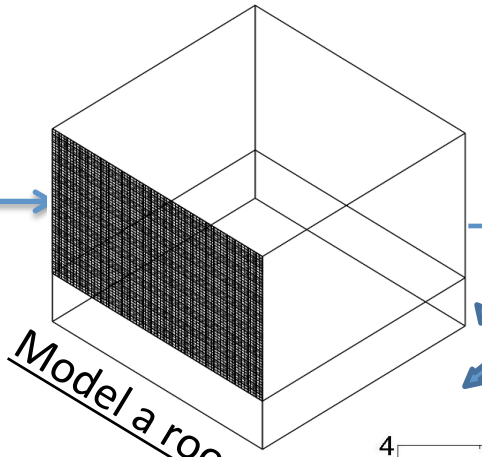


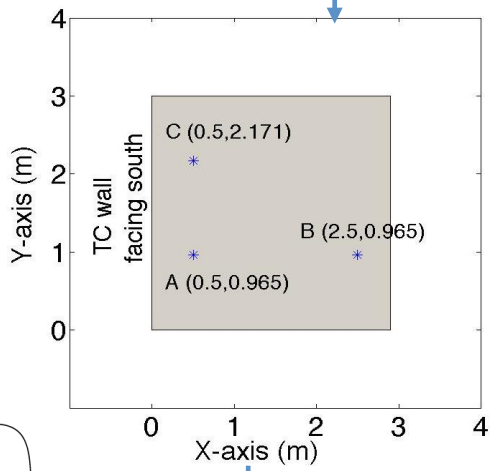
Markov chain Occupancy Profile

Algorithm for Energy Calculations

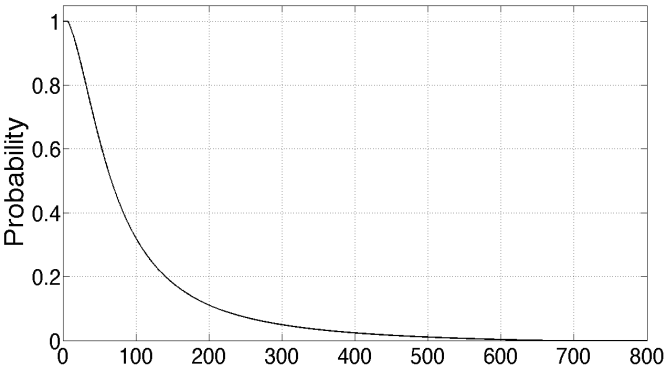
Start

Ray Trace through Translucent Concrete

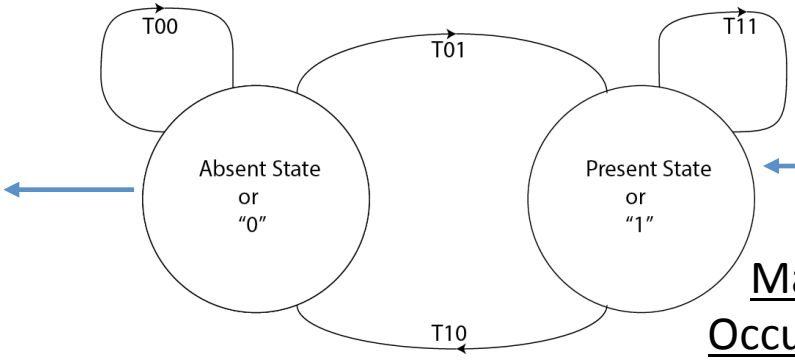




Light Switching Events



Light Switch-on at arrival



Markov chain Occupancy Profile

Algorithm for Energy Calculations

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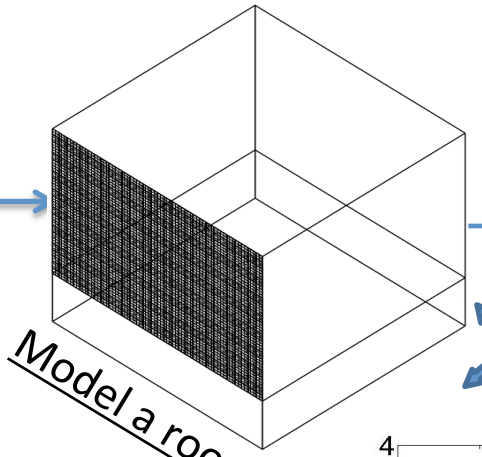
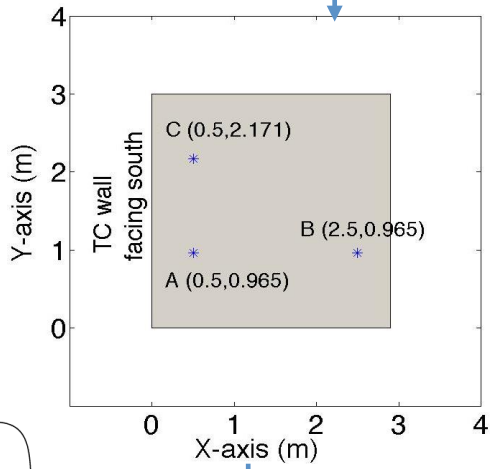
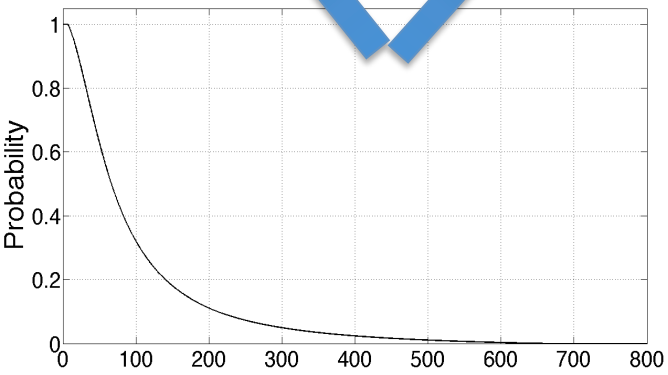


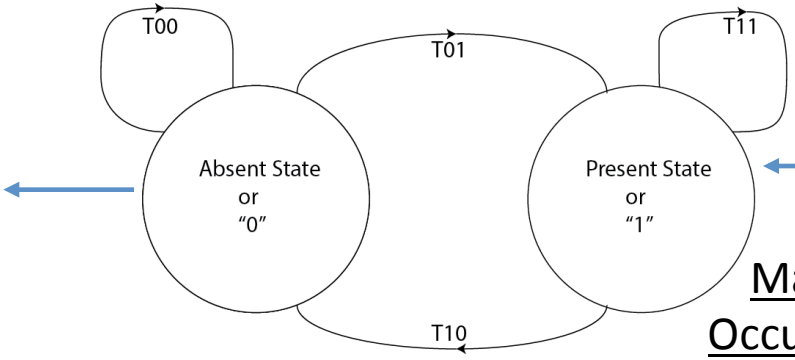
Light off; Energy saved

Light on; Energy spent





Light Switch-on at arrival



Markov chain Occupancy Profile

Results

- For fiber density of 5.59%, lighting energy saved is about 50% compared to constant use of T8-tubes.

- The energy saved increases to 65% for a fiber density of 10.6%.

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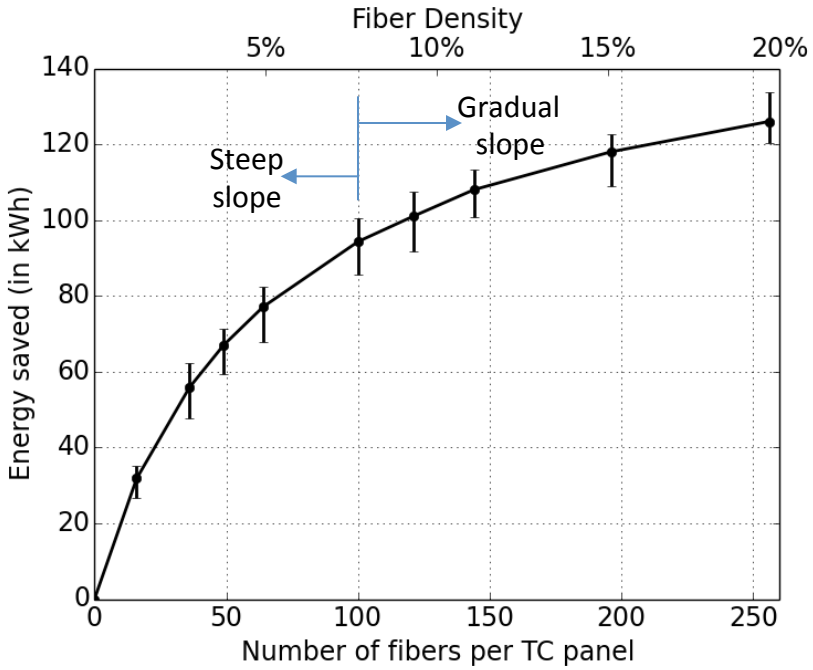


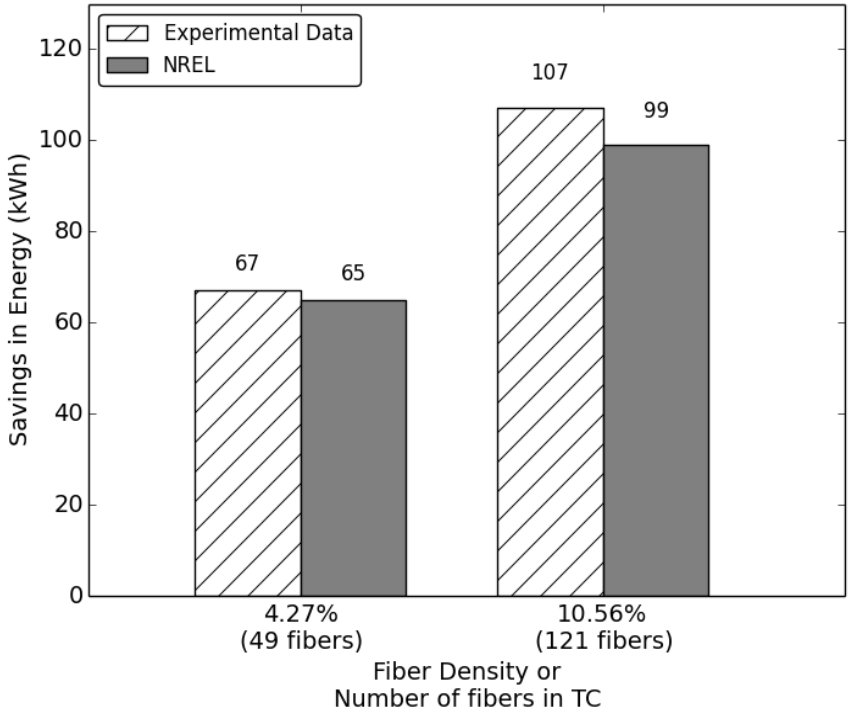
Energy savings with fiber density

Results

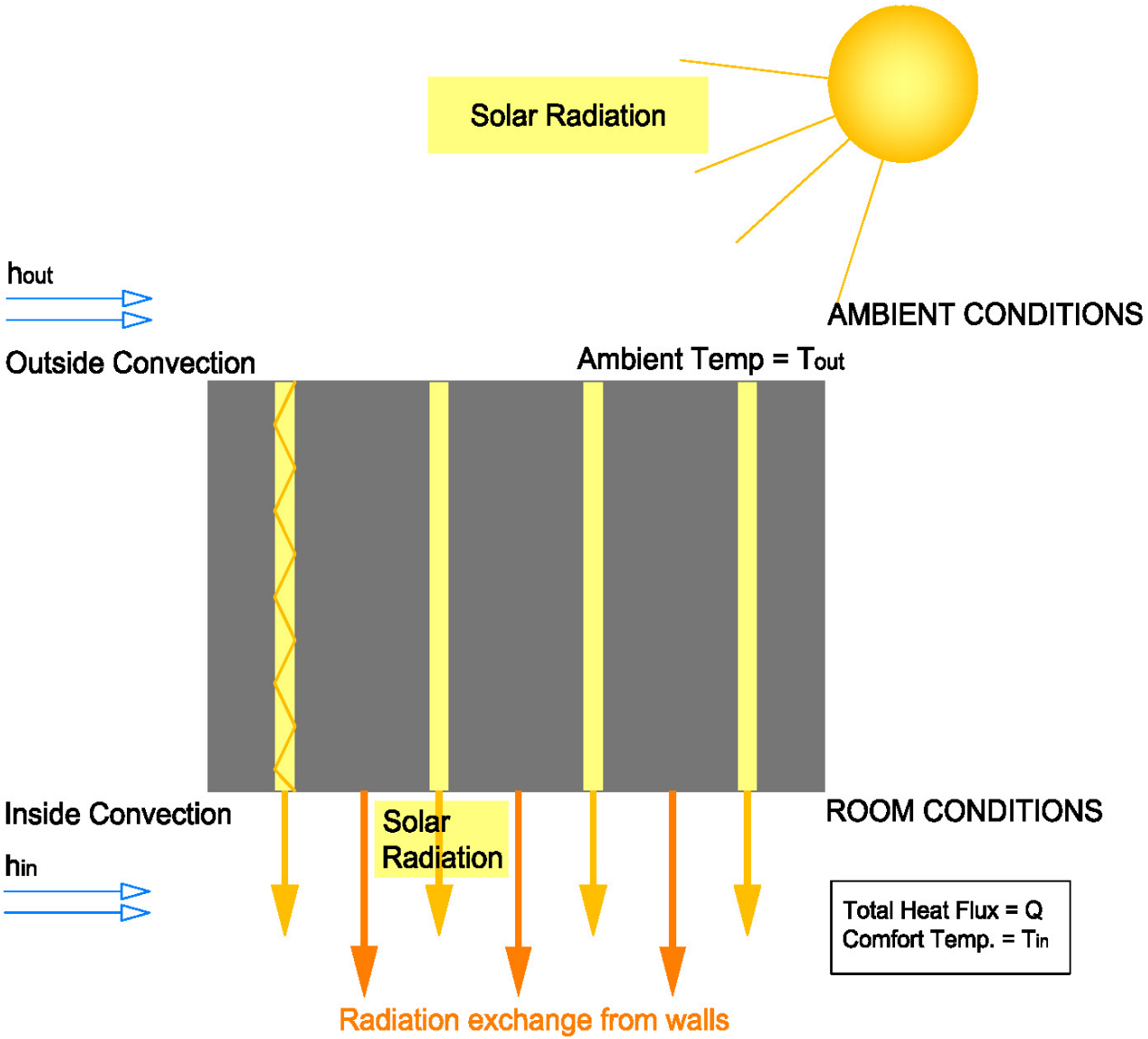
- For a fiber density of 5.59%, the lighting energy saved is about 50%.
- The energy saved increases to 65% for a fiber density of 10.6%.

1) Occupancy schedules for NREL, DOE-2 gives lower energy savings

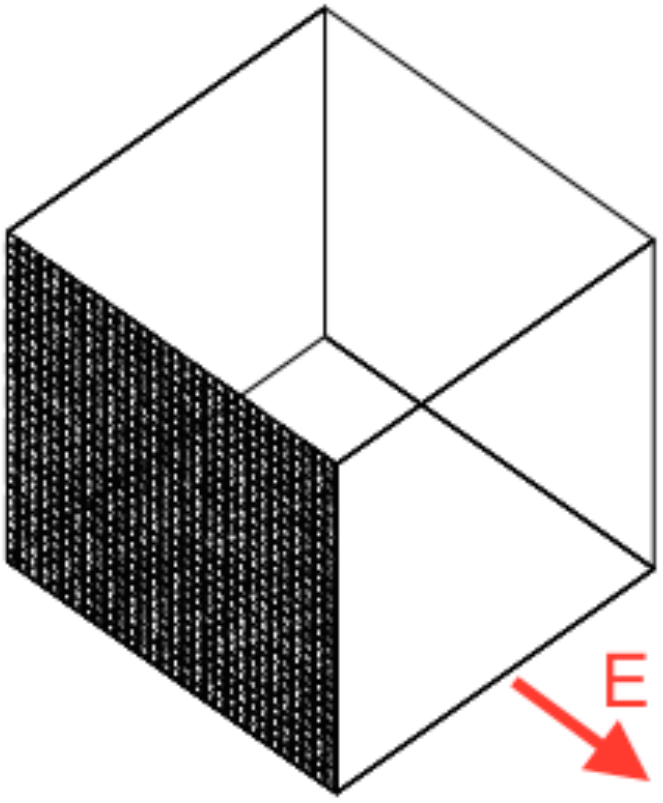
2) Does not account properly for occupancy during weekends.



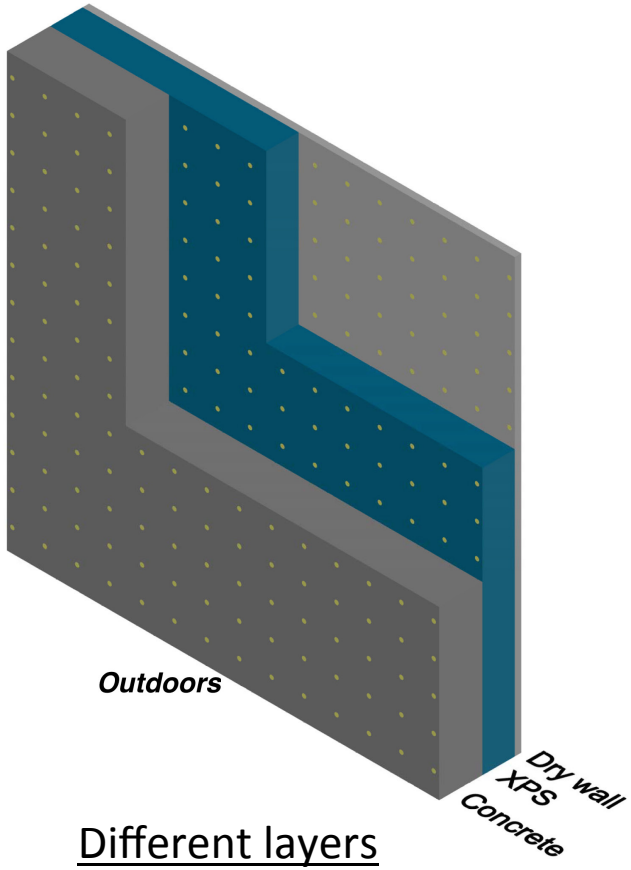
Thermal Behavior



Composition of wall



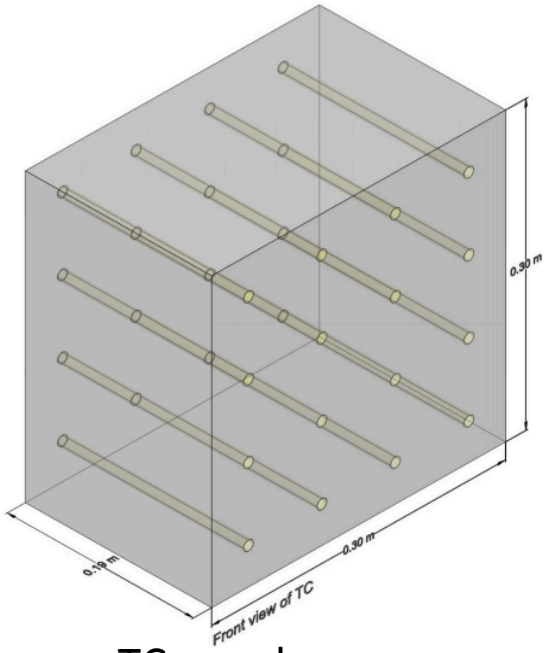
Model a room



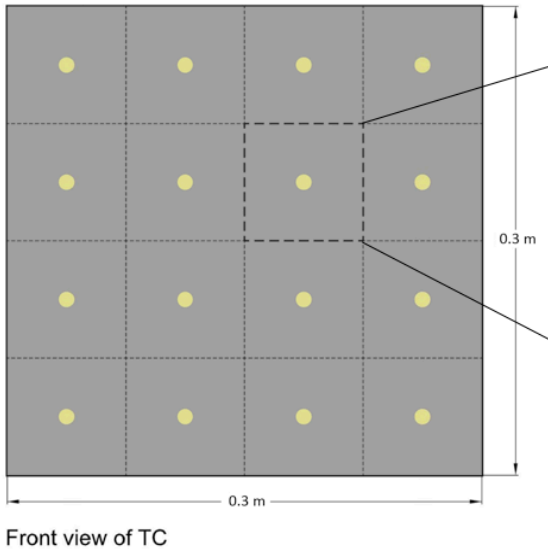
Different layers
of the wall,
R-value of opaque wall = 16

Representative Vol. Elem. (RVE)

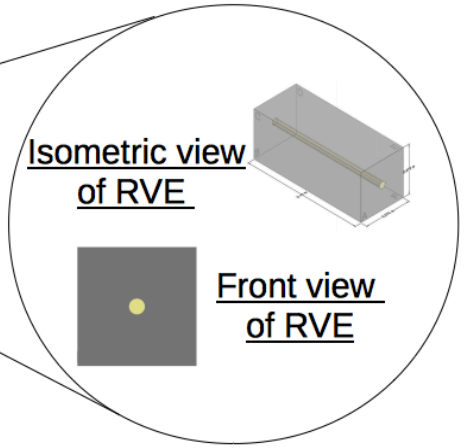
- Thermal behavior of opaque walls is easy and can be solved as a 1D problem.
- Thermal behavior of TC panel requires a 3D algorithm as the fibers passes through all layers.
- But 3D simulations are slow…divide the TC panel into repeating blocks or RVE.



TC panel



Front view



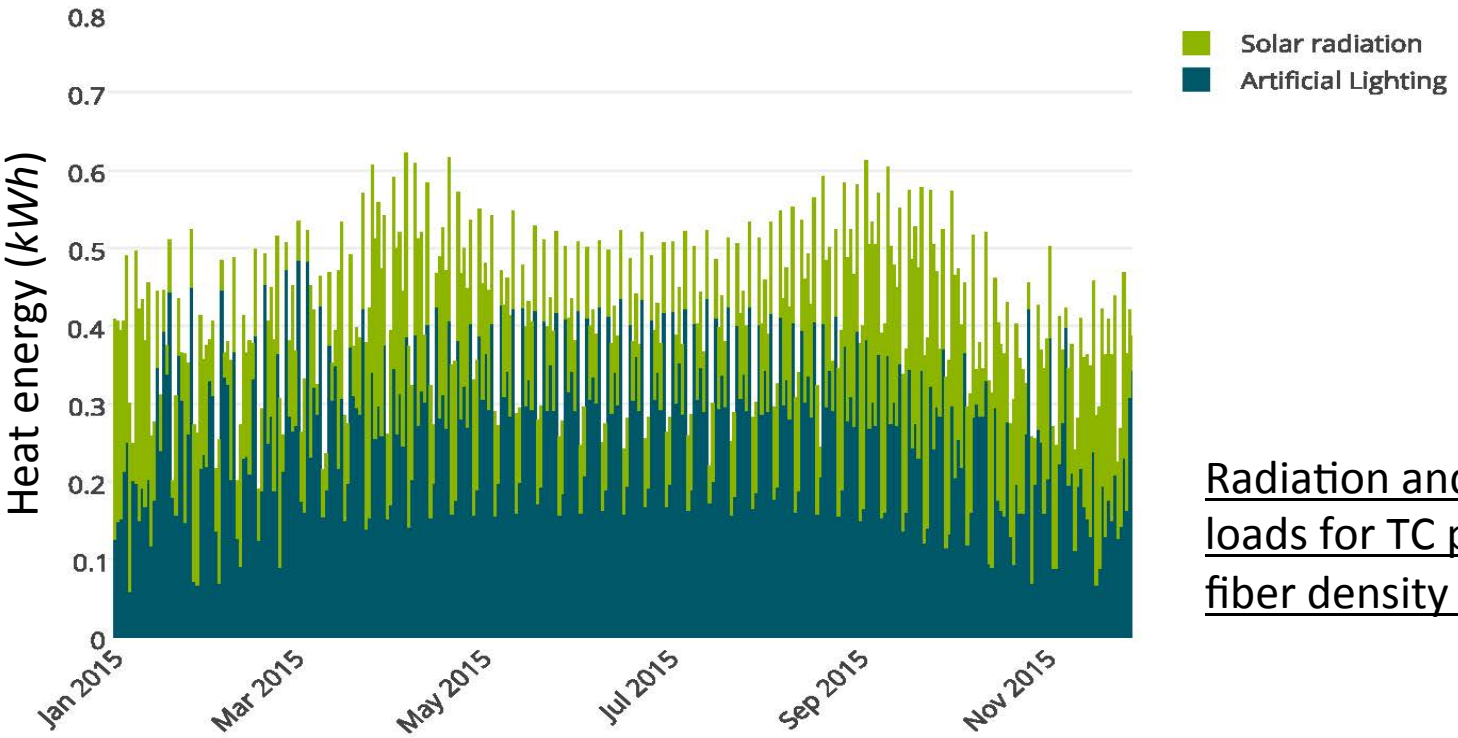
Repeating block or RVE

Heat Contribution

- Three sources of heat are considered in the room:
  - Heat Conduction through walls
  - Solar radiation through optical fibers
  - Heat dissipation by Fluorescent tubes

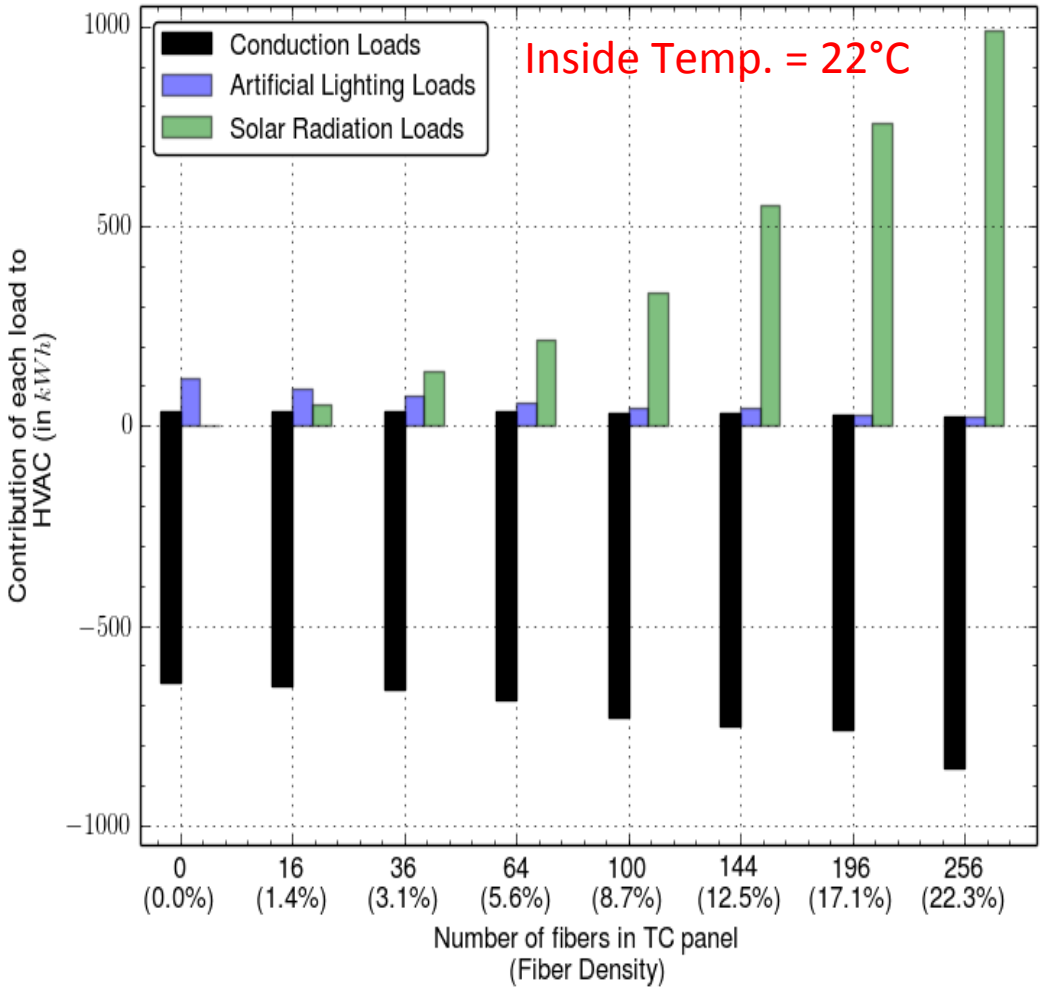
Radiation and Lighting loads

- Radiation loads depends on the fiber density ratio of the TC panels.
- Lower density of fibers is bad and so is higher density. Optimal density required.
- When solar radiation contribution is large, less artificial lighting is needed.



Radiation and heat dissipation loads for TC panels with 1.4% fiber density ratio.

Loads on HVAC



1) Heat added into room by conduction was small.

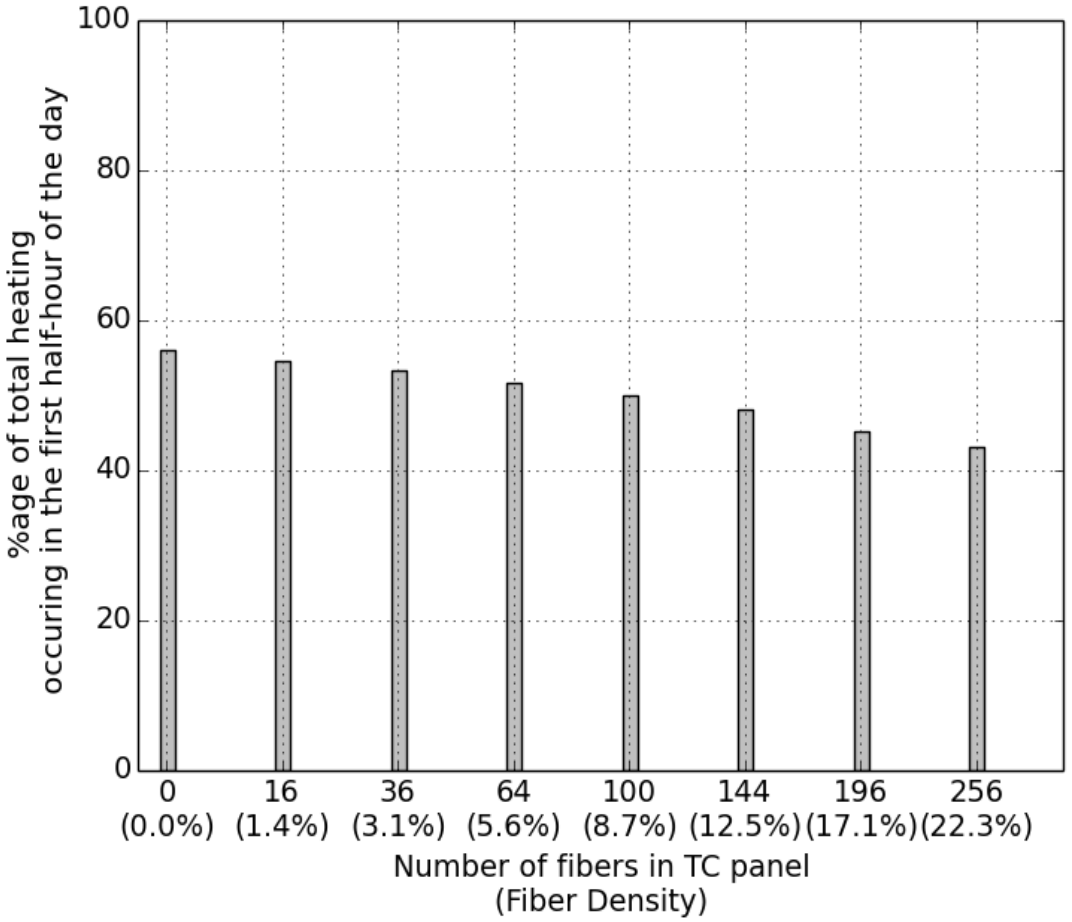
2) Cooling loads were majorly from solar radiation.

3) Heating loads due to conduction were substantial.

4) Heat dissipation from artificial lighting decreased as the fiber density increased.

Parameters for simulation:
R-value of wall = 16; R-value of fibers = 5.7;
Dissipation factor for tubes = 0.77; HVAC operation time: 8am-6pm

Heating loads



%age of heat removed at beginning of the day

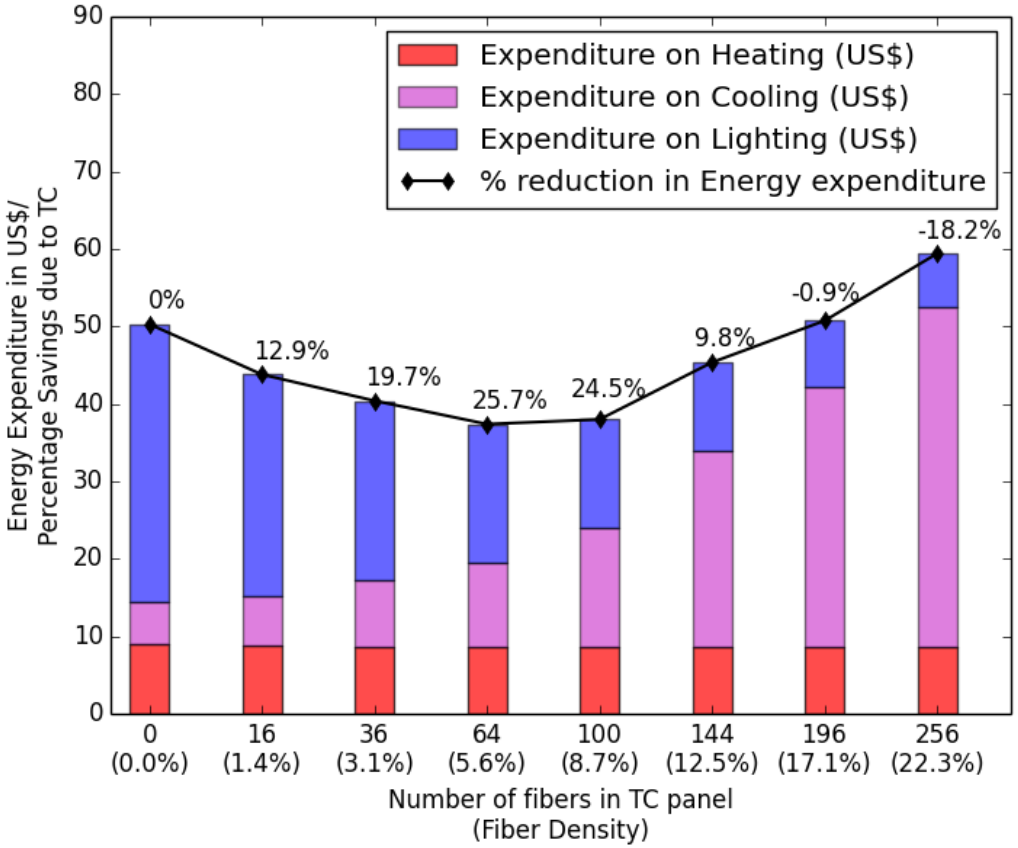
1) Heat removal due to conduction was large.

2) Most of the heat from room was removed during start of HVAC operation schedule (8 *am*-6 *pm)*.

3) The initial temperature at start of simulations (*i.e.* 8 *am*) were set to temperature at 7 *am*

4) Temperature at 7 *am* << 22℃

Results: Net savings



1) Combining the loads on HVAC with lighting requirements.

2) A fiber density ratio of 5.6% performs best in saving about 26% costs [Ahuja152] .

3) Small fiber density makes TC fabrication process easier.

4) High fiber density leads to monetary loss as solar radiation loads are high.

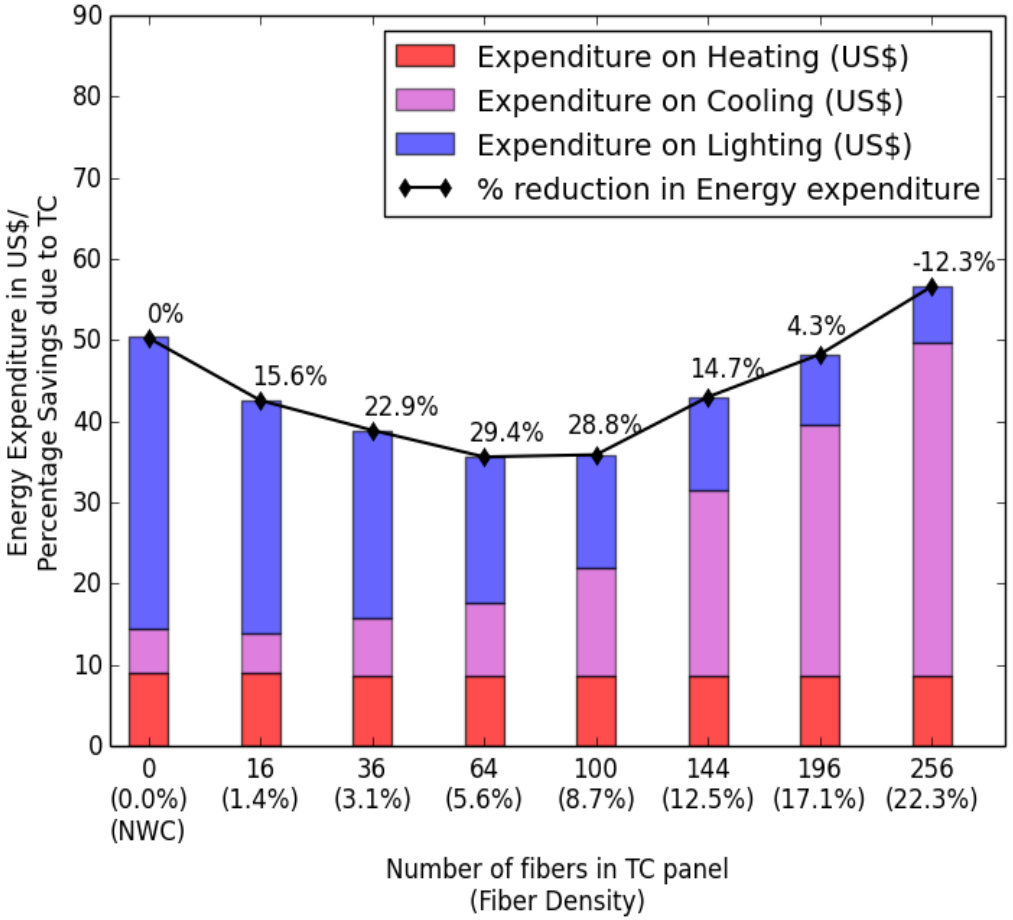
Parameters:

Heater *COP*: 3.5; Air-conditioner *COP*: 4.0

Utilities prices for SF Bay Area

Electricity: 23.3 *¢/kWh*; Natural gas: 5.4 *¢/kWh*

Results: Net savings



1) Lighweight composites used as building material.

2) Uses cenospheres which are hollow glass spheres and are produced as byproducts of coal combustion.

3) Cenospheres also enhance the thermal conductivity.

4) Expenditure reduces by 4% for fiber density of 5.6%.

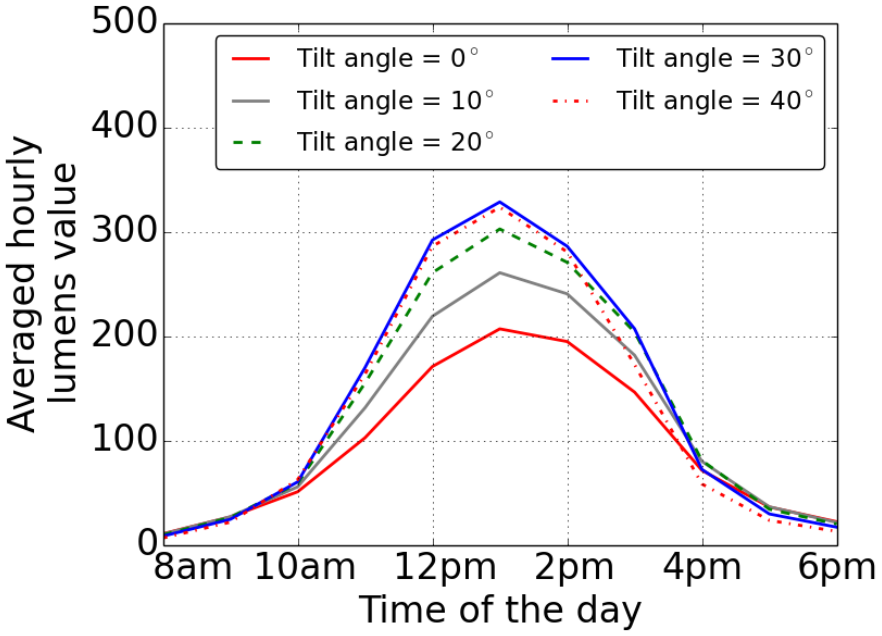
Parameters for TC w/cenospheres:
Thermal conductivity: 0.4 W/mK
Density: 1303 kg/m^3
Specific heat: 788 J/kgK

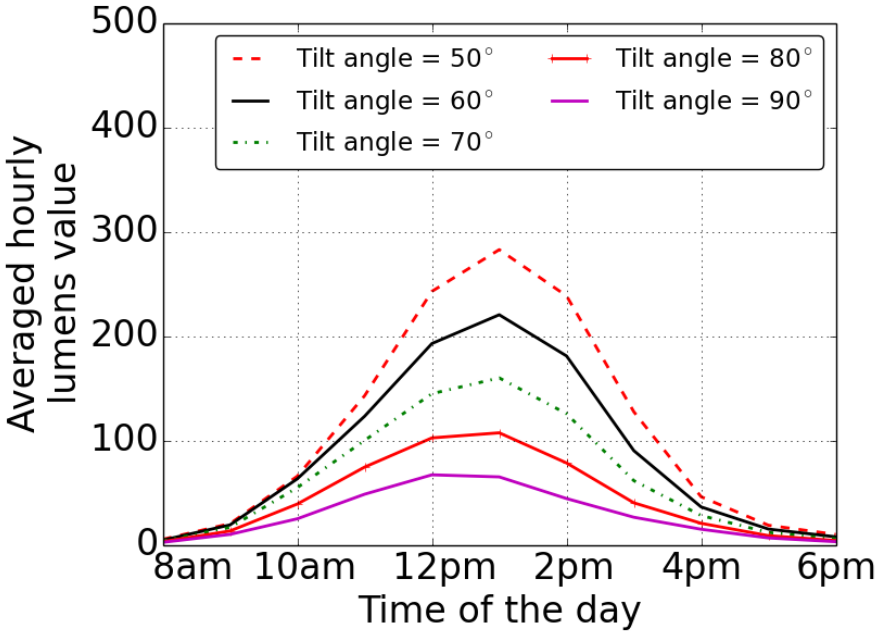
Conclusions

- Developed algorithms to analyze the thermal and optical behavior of translucent concrete.
- Translucent concrete shows promising results in saving energy.
- A fiber density of 5% can save ~50% on lighting energy.
- A fiber density of 5% can save ~24% total energy.
- Interfacing the algorithms with *EnergyPlus* to model complex situations.

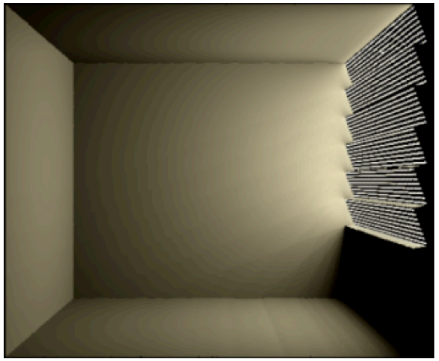
Future Work

Tilted Panels





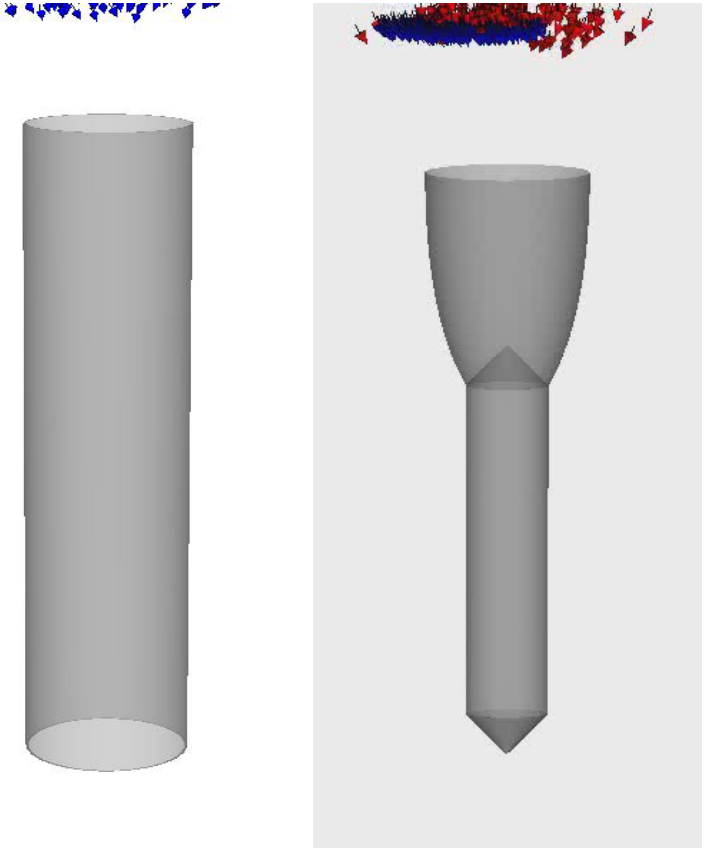
Avg. sunlight influx for whole year



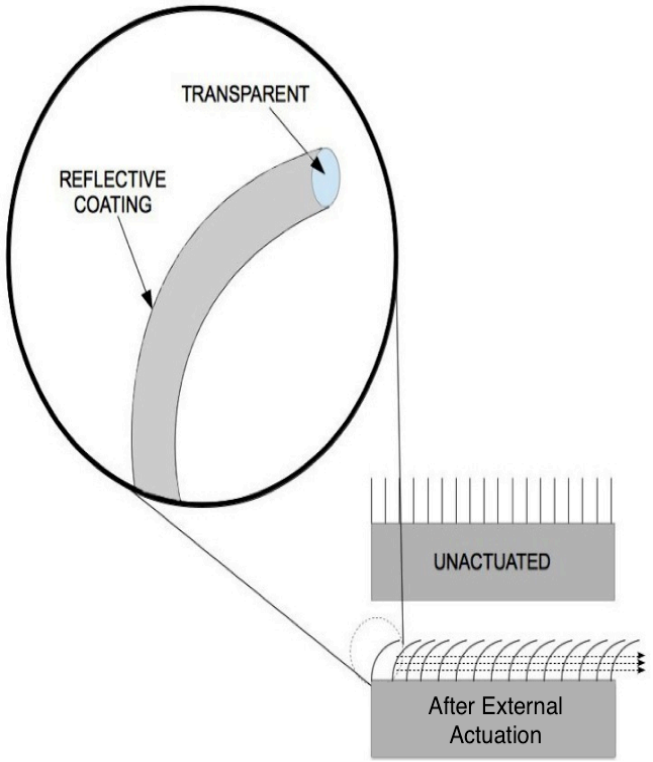
A TC wall with a tilt of 30° with horizontal transmitted maximum sunlight.

Capturing more daylight

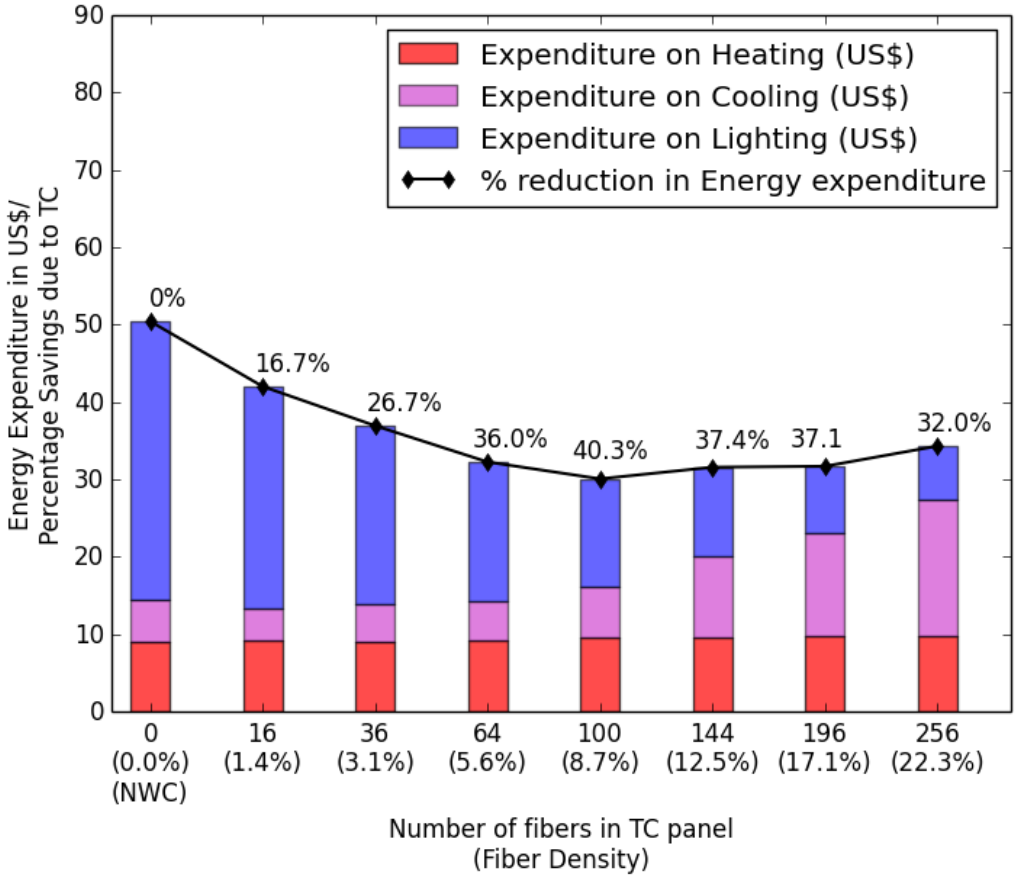
Modifying fiber shape



Using sun-tracking beams



Coating optical fibers



1) Potential in reducing energy usage by coating fibers to eliminate UV and infrared transmission.

2) Cuts down on solar radiation and increases savings to almost 40%.

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Thank you.

Questions?

Contact: aashishahuja@berkeley.edu